Find faults in cables with this:

By JIM ROWE

TDR Dongle For Oscilloscopes

How would you like to be able to track down faults in coaxial and other cables using time-domain reflectometer or 'TDR'? If you have a reasonably fast oscilloscope (20MHz or more), this low cost *TDR Dongle* will let you do a lot of basic cable fault finding very easily.

THE TIME-DOMAIN reflectometry (TDR) concepts behind this project are surprisingly simple, but are not frequently encountered outside specialist areas of electronics. If you need more information than is found in this article, then a reasonably straightforward introduction to the topic can be found here: **https://en.wikipedia.org/wiki/Time-domain_reflectometer**.

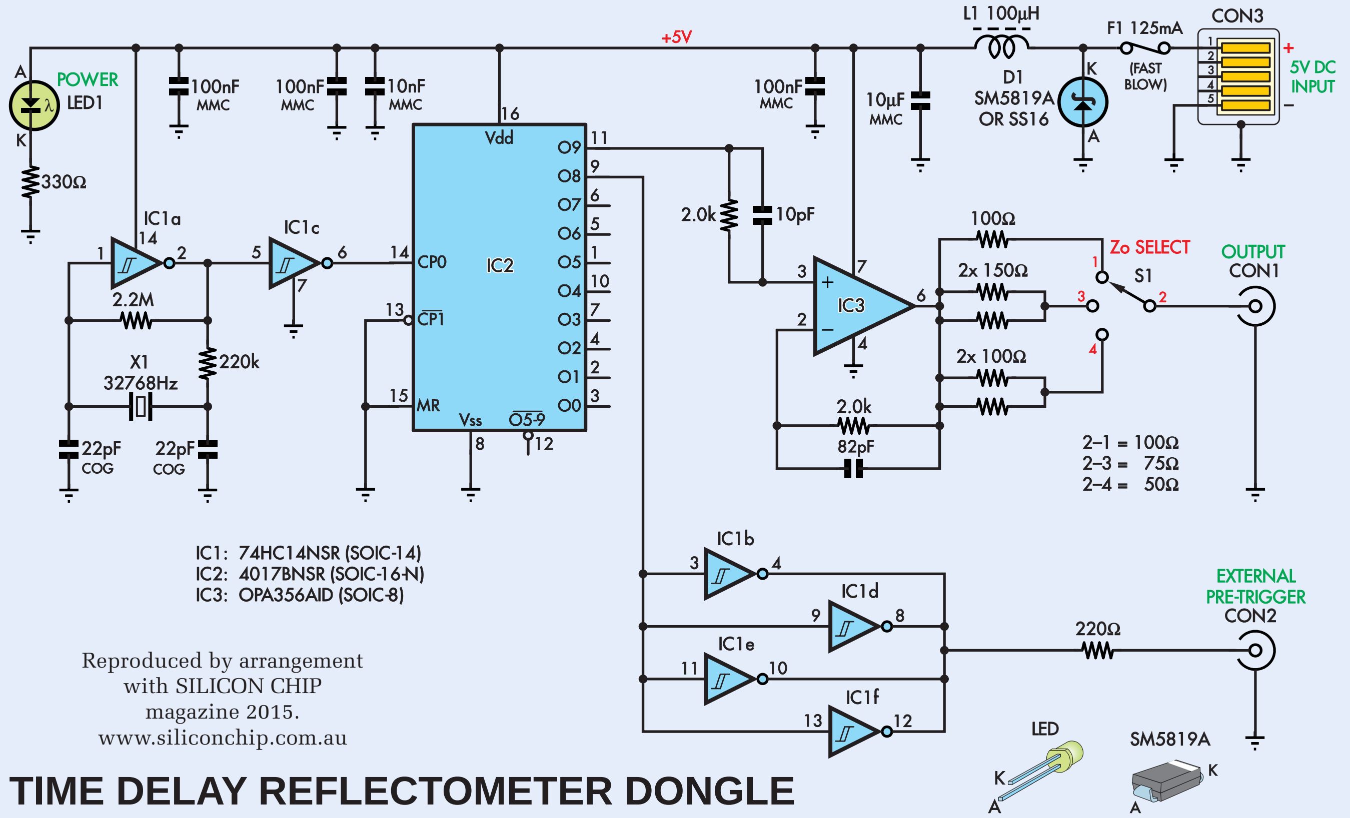
Most TDRs consist of two key components: (1) a voltage step or pulse generator to produce the electrical stimulus which is fed into the cable to be tested and (2) an oscilloscope to look for any reflections or echoes of that stimulus which may be returned by faults or discontinuities in the cable.

If the scope is reasonably fast and also calibrated, this allows you to work out factors like how far along the cable a fault or discontinuity may lie and the kind of fault it is.

High-end commercial TDRs have both of these key components built into the same case, plus some computing power to save you having to convert delay times into cable distances and step amplitudes into impedance levels. But they also carry a fairly stiff price tag, making it hard to justify their cost if you only need to use a TDR occasionally.

But if you have a reasonably good scope, you are well on the way to having a usable TDR. So in this article we're describing a voltage step generator capable of being used with almost any reasonably fast scope to produce a 'Step TDR'.

As shown in the photos, the project is based on a very small PCB with a small number of mainly SMD components mounted on it. This is housed in



IC1: 74HC14NSR (SOIC-14)
IC2: 4017BNSR (SOIC-16-N)
IC3: OPA356AID (SOIC-8)

Reproduced by arrangement
with SILICON CHIP
magazine 2015.
www.siliconchip.com.au

TIME DELAY REFLECTOMETER DONGLE

Fig.1: the complete circuit. A 32.768kHz crystal oscillator (IC1a) drives synchronous counter IC2 to produce 30.5µs-wide voltage steps which then pass through op amp buffer stage IC3. Switch S1 then selects one of three source resistances, to suit the impedance of the cable being tested.

a small ABS instrument case measuring 90 × 50 × 24mm – only a little larger than a USB dongle. And since it can be powered from a USB port of your DSO or PC (or a USB charger), that's why we have called it a *TDR Dongle* instead of a 'TDR Adaptor'.

Put simply, the *TDR Dongle* generates repetitive voltage steps which have a duration of 30.5µs (microseconds) at a rate of 3.278kHz – so there are gaps of 274.5µs between them. The 30.5µs duration of the steps is equal to 30,500ns, which allows for viewing reflections in commonly used 'solid PE dielectric' coaxial cables more than 3km long.

The *TDR Dongle's* main output delivers the steps with an amplitude of around 3.5-4V peak, via a choice of three source resistances: 50Ω, 75Ω or 100Ω. This allows it to be used for measurements on most commonly available cables and also means that the effective step amplitude at the input to the cable being tested will be around 1.75-2V peak when the generator's source resistance is correctly matched to the impedance (Zo) of the cable.

In addition to the main step output, there's a second external 'Pretrigger' output which provides a falling (negative-going) step output which is 30.5µs ahead of the main output step. The idea of this is that when you're using high sweep speeds to examine reflections relatively close to the step generator end of a cable, it should allow pre-triggering of your scope via its external trigger input, for greater reliability and improved resolution.

How it works

To see how the *TDR Dongle* works, turn to the circuit diagram of Fig.1. Only three ICs are involved, plus a handful of other components. IC1 is a 74HC14 hex Schmitt inverter, with one of its six inverters (IC1a) operating as a clock oscillator in conjunction with quartz crystal X1, a tiny SMD device resonating at 32.768kHz. A second inverter, IC1c, is used as an isolating buffer, to maintain a constant load on the output of IC1a.

The buffered 32.768kHz output from IC1c is then fed to the clock input of IC2, a 4017B synchronous Johnson decade counter which counts continuously. As a result, output O9 of IC2 (pin 11) goes high for 30.5µs after every nine clock pulses – during which each of the other outputs (ie, O0 – O8) goes high in turn.

So pin 11 of IC2 switches high every 305µs and remains high for 30.5µs each time. This is how our voltage steps are generated.

These voltage steps from pin 11 of IC2 are fed to the non-inverting input of IC3, an OPA356 high-speed video amplifier being used here as a cable driver. The connection is not made directly but via a paralleled 2.0kΩ resistor and 10pF capacitor combination.

IC3 is connected as a unity-gain voltage follower, with the paralleled 2.0kΩ resistor and 82pF capacitor in the negative feedback line being included to achieve high stability, a short rise-time and minimum overshoot. So the output voltage step appears at pin 6 with an amplitude of about 3.5V, limited by IC3's input common-mode range of GND to Vcc – 1.5V.

Switch S1 allows selection of one of three possible output series resistances: 50Ω, 75Ω or 100Ω. This allows the source resistance of the step generator to be matched to the characteristic impedance (Zo) of the type of cable

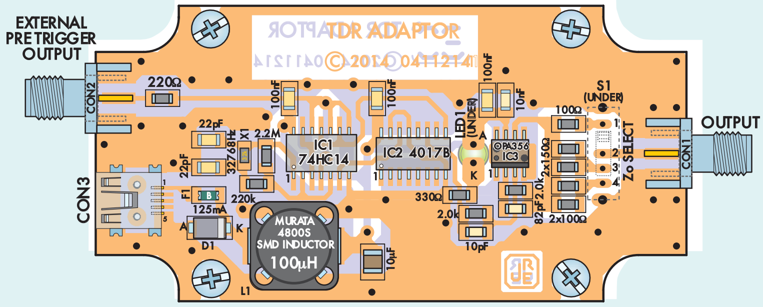


Fig.2: the PCB overlay diagram, shown actual size. Most of the parts are SMDs and are mounted on the top of the PCB. LED1 and selector switch S1 are mounted underneath.

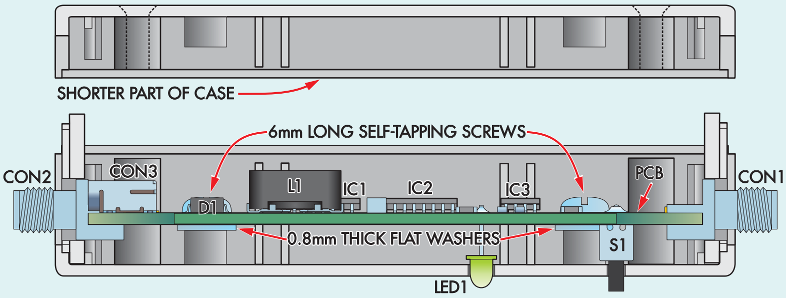
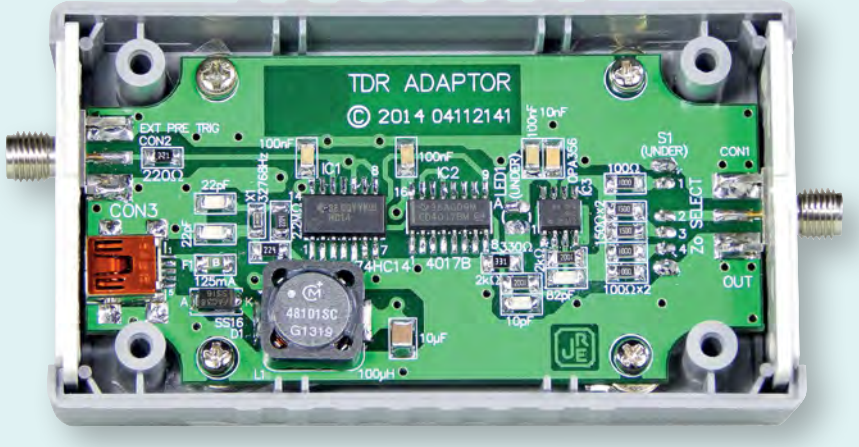


Fig.3: an internal side view showing how the *Dongle's* PCB assembly is mounted in the case. Note that a 0.8mm-thick flat washer needs to be placed on the top of each moulded PCB mounting post, as shown.



All of the SMD components used in the *TDR Dongle* can be seen in this photo, reproduced close to actual size. Use this together with the diagrams above as a guide to assembly.

you want to test. The output steps pass through the selected resistance to appear at output connector CON1, an SMA socket.

The external pre-trigger output is derived from the O8 output (pin 9) of IC2, which goes high 30.5µs before the O9 output and also remains high for 30.5µs – falling to zero just before each main step.

The remaining inverters inside IC1 are connected in parallel and used as an inverting buffer for the pre-trigger pulses, with their buffered output taken to CON2 via a 220Ω protective series resistor.

So the output pulses from CON2 are negative-going, rising back to zero simultaneously with the rise of each main output step.

The rest of the circuit is straightforward. The 5V DC power needed by the circuit is brought in via CON3, a mini-USB type B socket. Fuse F1 and diode D1 are provided purely for reverse polarity protection, while L1 and the 10µF capacitor are used for filtering the +5V line. LED1 is used to indicate when the adaptor is powered up and operating.

Construction

As stated, all the parts are mounted on a small PCB, available from the *EPE PCB Service*, coded 04112141 and measuring 81 × 41mm. Fig.2 shows the parts layout diagram.

The only parts which aren't surface-mount devices (SMDs) are switch S1 and LED1. These are both in through-hole packages and are mounted on the underside of the PCB. Note that S1 is actually a sub-miniature slider switch, although we've shown it in the schematic of Fig.1 as a rotary switch for greater clarity.

We suggest that you add the parts to the PCB in the following order, to make it easier:

- Fit power connector CON3, soldering its five tiny connection leads to their matching pads on the PCB before you solder its four 'feet' to the larger pads.
- Fit the SMD resistors to the PCB, followed by the capacitors.
- Fit fuse F1, followed by diode D1 which goes alongside it.
- Solder IC1, IC2 and IC3 to the top of the PCB, taking care with their orientation and also making sure that all their pins are soldered to their matching pads. Use solder wick and no-clean flux paste to remove any inadvertent solder bridges between the pins.
- Filter inductor L1 is the last SMD component to add to the board. That's because it's the largest and tends to limit access to some of the smaller components if it's fitted earlier.

  Note that L1 is mounted with its two continuous contact strips on the east and west sides (with the PCB oriented as shown in Fig.2), so that they can be soldered to the pads on the top of the PCB.
- Install LED1 and switch S1, the two through-hole parts. These mount under the PCB, with their leads and pins passing up through the matching holes and soldered to the pads on the top of the PCB.

  Note that S1 should be pushed up until its underside is hard against the bottom of the PCB, before soldering its pins and its two end mounting lugs to the top copper. By contrast, LED1 is not pushed hard up against the PCB, but fitted with the underside of its lens about 3-4mm below the PCB. This ensures that lens just protrudes through its matching hole in the case after final assembly.

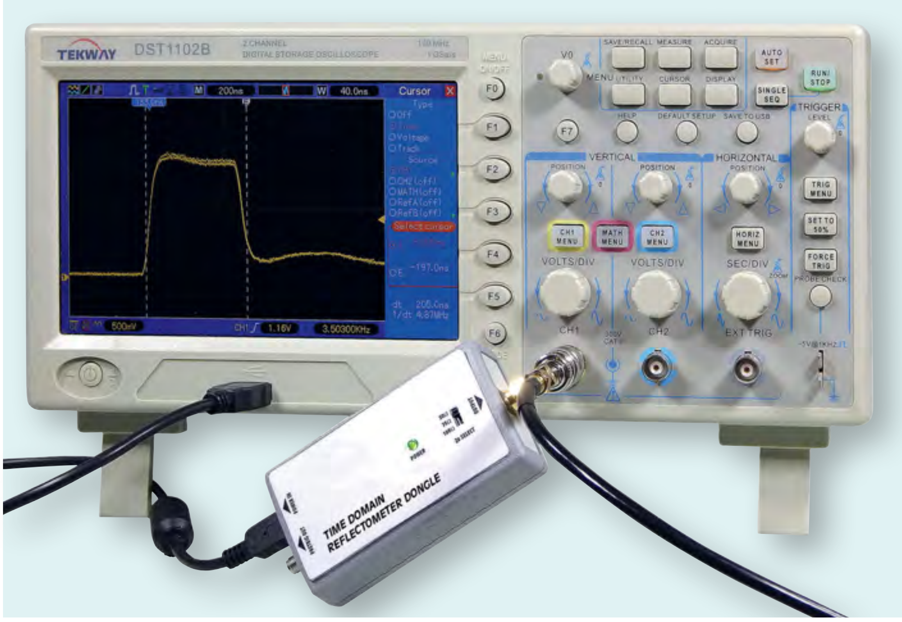
- Fit connectors CON1 and CON2. These are 'straight through' SMA sockets which mount on the edge of the PCB at opposite ends. When mounting these, it's a good idea to first solder their centre pins to the matching pads on the top of the PCB, so they are then held in position while you solder their outer earth.

The internal side view diagram of Fig.3 should help in making the above description a little clearer. The PCB assembly should now be complete and can be put aside while you prepare the case.

Preparing the case

There's not a lot of work involved in preparing the case, as shown by the drilling and cutting diagram of Fig.4. There are only five holes in all: two in the deeper part of the case (which becomes the top of the *TDR Dongle*), two in the lefthand end panel (for access to CON2 and CON3), and the remaining one in the righthand end panel for access to CON1.

There's one point to note before you start on the rectangular holes in the end panels. The end panels are effectively polarised, as shown in Fig.4 – they're tapered between one longer side to the other, which means that they'll only fit into the deeper part of the case one way around (the side with the small central notch in the flange must face upwards, towards the less-deep part of the case).



This photo shows the *TDR Dongle* being used with a Tekway DST-1102B DSO. It's coupled to the scope's CH1 input via a BNC plug-to-plug adaptor. Because the *Dongle* is very light, this is a good way to use it.

So make sure you have the end panels oriented correctly before you mark the positions of the holes and (especially) before you begin to drill and cut them out.

Only one of the five holes is circular – the 3.5mm diameter hole for LED1 in the main part of the case. The others are all rectangular, so you'll need to use a small (1.5-2mm) drill to make a series of holes around the inside of their rectangular outlines first, to allow you to cut away the material inside. Then you can use small jeweller's files to neaten them up and bring them out to their final shape.

Once you have made all of the cutouts in the case and its end panels, you can make a front panel to attach to the top of the case and to this end we've prepared the small artwork shown as Fig.5. This can be photocopied and covered with clear adhesive tape to protect it from dirt and finger grease, before cutting it to size and then attaching it to the deeper part of the case using double-sided tape or silicone.

Alternatively, you can download the artwork as a PDF file from the *EPE* website and print it out.

Final assembly

Once you have prepared the case, the final assembly is straightforward. The first step is to place the deeper part of the case down on the workbench, with its outer dress front panel underneath. Then place a small flat washer (0.8mm thick, 3.5mm inside diameter) centrally on the top of each

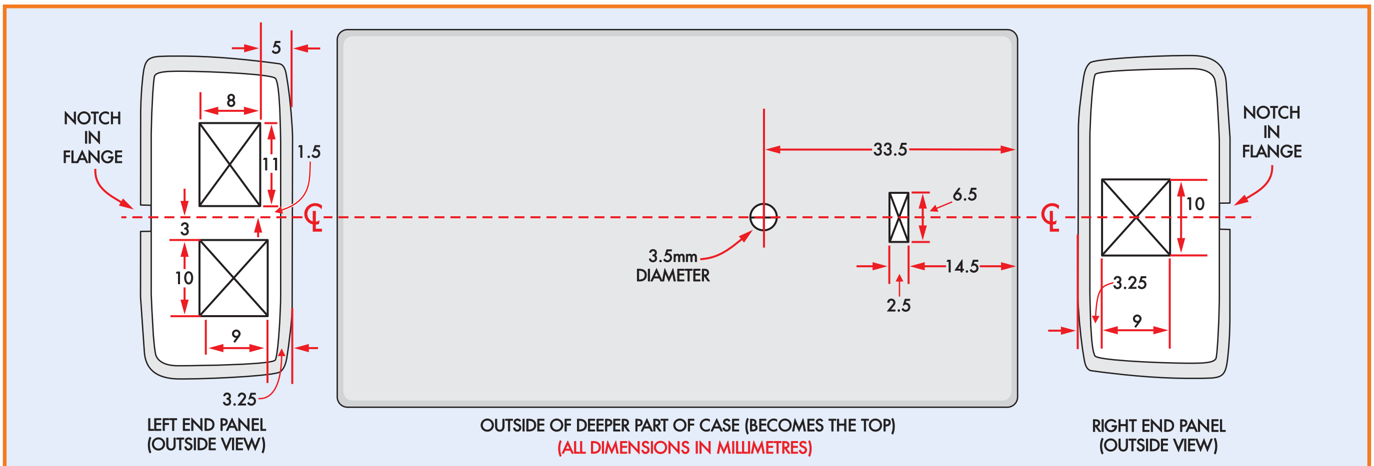


Fig.4: the drilling and cutting details for the case. Note that the end panels are polarised – make sure you orient them as shown before you make their rectangular cutouts.

Parts List

1 ABS case, 90 × 50 × 24mm
1 double-sided PCB, available from the *EPE PCB Service*, code 04112141, 81 × 41mm
2 SMA sockets, edge-mounting (CON1,2)
1 mini USB type B socket, SMD, FCI 10033525-N3212MLF (CON3)
1 100µH 1.6A SMD inductor (L1), Murata 48101SC
1 mini slider switch, SP3T (S1), C&K OS103011MS8QP1
1 32768Hz crystal, SMD (X1)
1 125mA fast blow 1206 SMD fuse (F1), Littelfuse 0466.125NR
4 6G × 6mm self-tapping screws
4 3.5mm ID flat washers, 0.8mm thick

Semiconductors
1 74HC14NSR hex Schmitt-input inverter, SOIC-14 package (IC1)
1 4017BM decade counter, SOIC-16-N package (IC2)
1 OPA356AID video amplifier, SOIC-8 package (IC3)
1 3mm green LED (LED1)
1 60V 1A Schottky diode, DO214AC SMD package (D1) (SS16 or SM5819A)

Capacitors
1 10µF MLCC, SMD 1210, X7R dielectric, 16V rating
3 100nF MLCC, SMD 1206, X7R dielectric, 50V rating
1 10nF MLCC, SMD 1206 X7R dielectric, 16V rating
1 82pF ceramic, SMD 1206, C0G/NP0 dielectric, 50V rating
2 22pF ceramic, SMD 1206, C0G/NP0 dielectric, 50V rating
1 10pF ceramic, SMD 1206, C0G/NP0 dielectric, 50V rating

Resistors (0.25W 1% SMD 1206 pkg)
1 2.2MΩ
1 220kΩ
2 2.0kΩ
1 330Ω
1 220Ω
2 150Ω
3 100Ω

of the four moulded-in PCB mounting posts. These are needed to provide additional spacing.

Next, fit the two end panels over the connectors at each end of the PCB and lower the PCB and end panels together into the deeper part of the case, with the end panels fitting into the moulded slots at each end. Do this carefully, so you don't accidentally knock the spacing washers off their posts. You should find that when the PCB is sitting on the washers, LED1 and S1's actuator will just be protruding through their holes in the front panel underneath – see Fig.3.

After that, it's simply a matter of fitting four small 6G × 6mm self-tapping screws to secure the PCB assembly and then fitting the other part of the case. This case section is also effectively polarised, so you need to fit it the correct way around.

The final step is fitting the four 15mm-long countersink-head self tapping screws supplied with the case, to hold everything together. Your *TDR Dongle* should then be complete and ready for use.

Connecting up

The first step in connecting the *TDR Dongle* is to provide it with 5V DC power, via a standard USB type A to mini USB type B cable (note that the cable should have a USB-Mini type B plug at the *Dongle* end, not a USB-Micro plug). The mini plug end mates with CON3 on the *Dongle*, while the type A plug on the other end will mate with a USB port on your scope, your PC or even a USB charger plugpack.

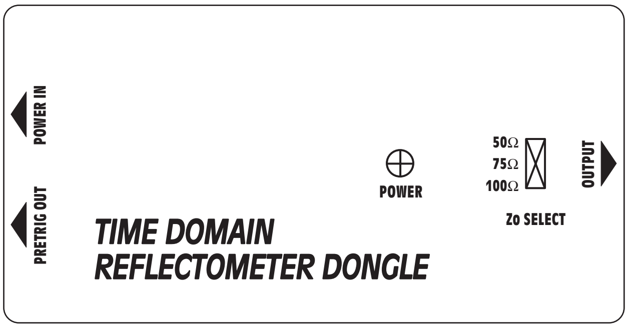


Fig.5: the full-size front-panel artwork for the *TDR Dongle*, reproduced. It can be photocopied or you can download it in PDF format from the *EPE* website and print it out.

Now you need to make the connections between the main output of the *TDR Dongle*, one input of your scope and the input end of the cable you want to test. This is not quite as straightforward because to a large extent, the neatest and most efficient way to make the connections will depend on the connectors being used on the cable to be tested.

The main point to keep in mind is that both the scope input and the input end of the cable to be tested should be connected to the output of the *TDR Dongle* using the smallest possible number of connectors, 'series adaptors' and couplers. That's because connectors, adaptors and couplers always introduce a small discontinuity of their own.

The two sample configurations shown in Fig.6 are intended to guide you in using the *TDR Dongle* to test cables fitted with two of the most common types of connector. The upper configuration shows the neatest and most efficient approach when you're going to test cables with BNC connectors, while the lower one shows the most efficient approach when the cables to be tested are fitted with SMA connectors.

Note that in both cases we've shown the cable running to the scope input fitted with BNC connectors, because most scope inputs are fitted with BNC connectors anyway.

As you can see, the simplest approach in the 'BNC world' is to use an SMA plug-to-BNC socket adaptor right at the *TDR Dongle's* output, connected directly to a BNC plug-to-2 × BNC sockets T-adaptor. The cable to be tested then attaches to one of the T-adaptor's sockets, while the short cable running to the scope input attaches to the other socket.

On the other hand, when the cable(s) to be tested have SMA connectors, the simplest approach is to connect an SMA plug-to-2 × SMA sockets T-adaptor directly to the *Dongle's* output socket, as shown in the lower configuration of Fig.6. The cable to be tested is then attached to one of the T-adaptor's sockets, with the scope input cable connecting to the other socket via an SMA plug-to-BNC socket adaptor.

What if you want to test cables fitted with N-type or F-type connectors? In

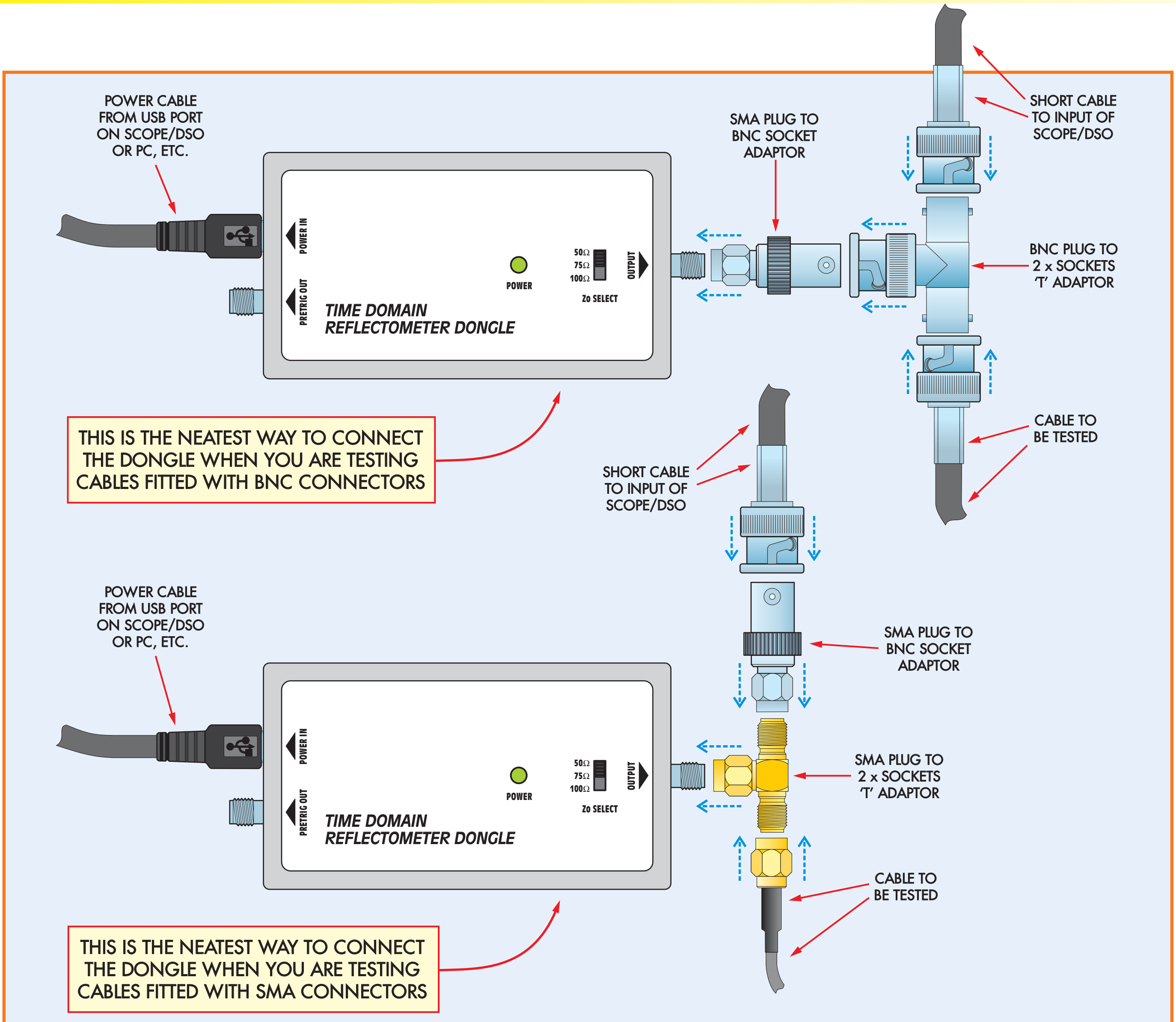


Fig.6: here are two neat and efficient ways to connect the *Dongle* when using it to test cables. A BNC plug-to-plug adaptor can be used instead of the short cable running to the scope/DSO input, to minimise reflections even further.

these cases, the simplest approach is to again use the lower configuration in Fig.6. However, instead of connecting the cable to be tested directly to the lower socket of the SMA T-adaptor, connect it via an SMA-to-N-type or an SMA-to-F-type adaptor.

The same approach will also apply if you need to test cables with old UHF connectors or even Belling-Lee (TV RF) connectors.

What about Ethernet cables?

How could you use the *TDR Dongle* to check Ethernet or other twisted-pair cables fitted with RJ-45 or similar connectors? To do this, you'd probably need to make up a special T-adaptor of your own, perhaps with one or more switches to allow you to select each cable pair to test them. You may also need to build in one or more additional resistors in series with the *TDR Dongle's* output, to allow better matching to the higher Zo of the cable pairs.

So using the *TDR Dongle* is likely to call for a range of cable adaptors. Fortunately, many of these are available from the usual suppliers, although you will probably have to order some of the more exotic adaptors from firms like element14. To help you in this regard, here are the element14 order numbers for two of them:

1) SMA plug-to-BNC socket adaptor, (50Ω): order code 116-9564
2) SMA plug-to-2 × SMA socket T-adaptor: order code 213-5972

Putting it to use

There's not a great deal involved in using the *TDR Dongle* for cable testing. The main steps are these:

1) Connect it up as shown in one of the configurations of Fig.6.
2) Set S1 on the *TDR Dongle* (Zo SELECT) to match the characteristic impedance of the cable you want to test.
3) Power up your scope and set the timebase's speed to around 1µs/division and a vertical sensitivity which gives about 5.0V full deflection.
4) Set the scope's triggering for a rising edge, at a level of around 1.25V. Alternatively, if you're going to make use of the *TDR Dongle's* pretrigger output connected to the scope's external trigger input, set it for a falling edge and a level of around 2.5V.
5) Apply power to the *TDR Dongle* and observe the screen of the scope, looking for any reflection steps if there are any to be seen.

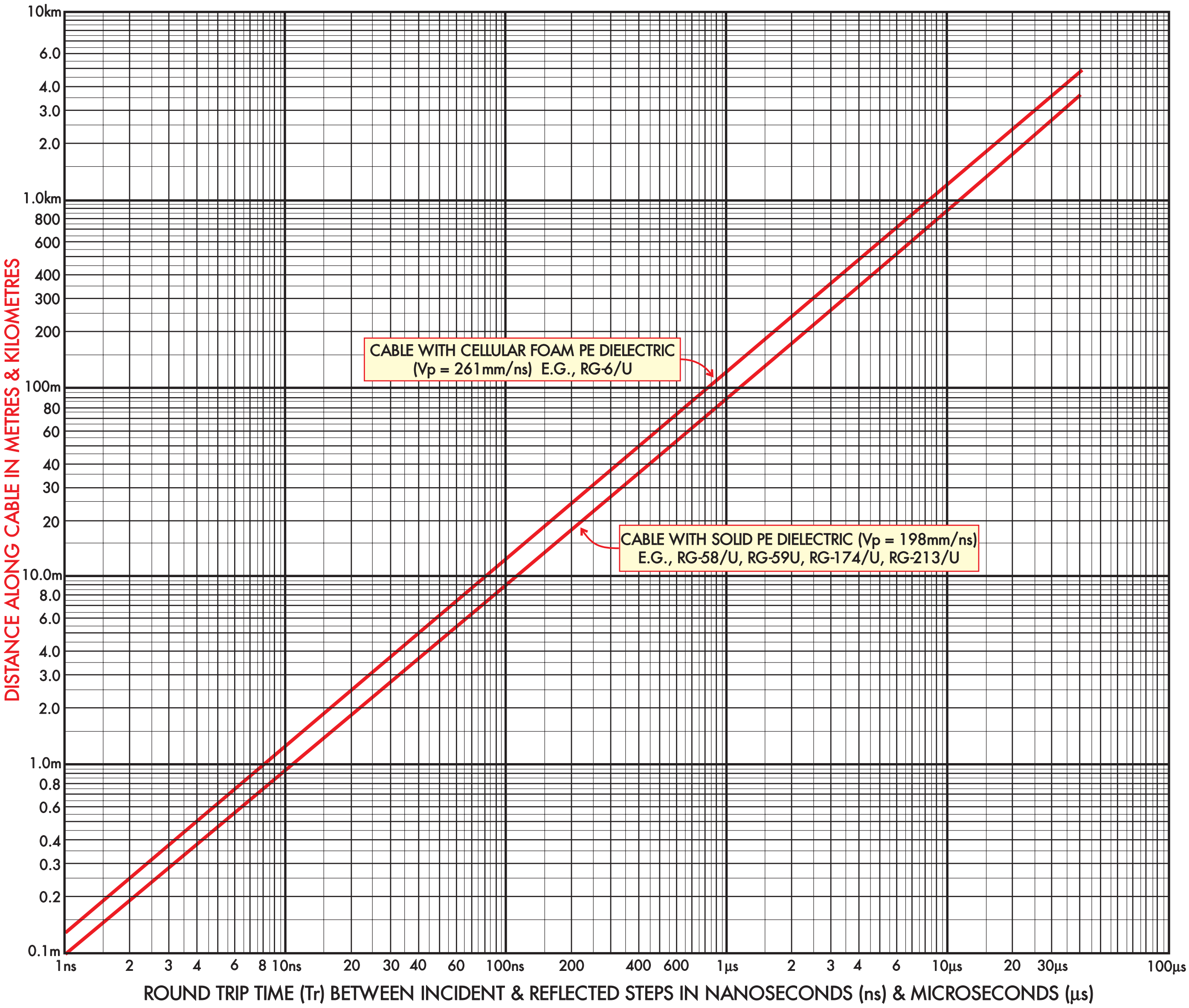


Fig.7: this graph makes it easy to work out the distance of a discontinuity along a cable once you know the round-trip reflection time as displayed on a scope. The lower red line should be used for solid PE dielectric cables (the most common type), while the upper line is for cables using cellular foam PE dielectric.

6) If any reflection steps are evident, you should then be able to determine what kind of discontinuity they're caused by and by measuring the time between the *Dongle's* incident step and the reflection step, you should be able to calculate its distance along the cable – knowing the cable's velocity factor.

This photo shows three of the cable adaptors you're likely to need when using the *TDR Dongle*: a 50Ω SMA plug-to-BNC socket adaptor (left); an SMA plug-to-2 × SMA sockets T-adaptor (centre); and an N-type socket-to-SMA plug adaptor (right).

To help you in working out the distance of a discontinuity along the cable from the time difference between the incident and reflected steps without having to turn to your calculator, we have prepared the graph shown in Fig.7. This shows the relationship between inter-step transit time (Tr) and the corresponding distance along the cable, for the two most common types of coaxial cable in current use.

You will also be able to work out the effective impedance of any particular continuity from the relative amplitudes of the incident step Ei and the reflected step Er – together with the polarity of Er, of course. But you're going to have to work this out using the following expression:

$$Z_{load} = -Zo \times (Ei + Er) \div (Er - Ei)$$

If your cable has either an open circuit or a short circuit as the discontinuity, this will be very easy to spot. With an open circuit, Er will have the same amplitude as Ei and the same polarity. A short circuit will result in Er again having the same amplitude as Ei but in this case with reversed polarity.

Some test example are shown in the scope screen grabs of Figs.8-11. These were captured using the prototype

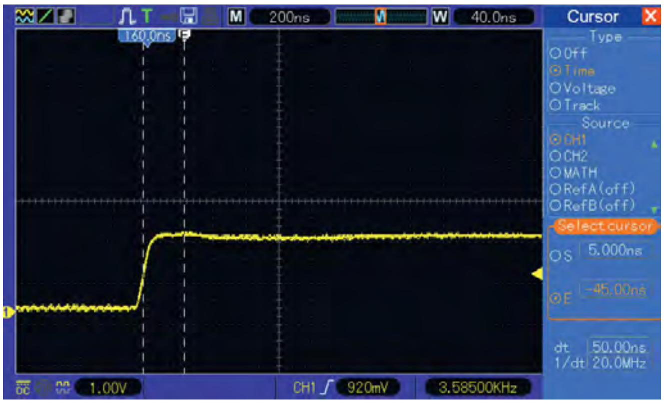


Fig.8: this screen grab shows the display when the *Dongle* was used to check a 4.6m-long SMA-SMA cable correctly terminated at the far end with a 50Ω termination. There are no reflections!

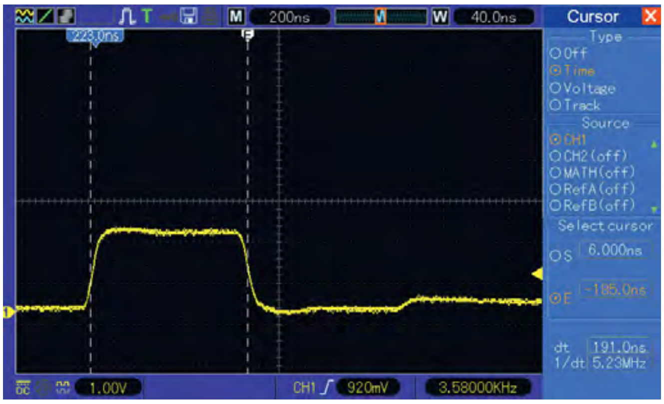


Fig.9: in comparison with Fig.8, this scope grab shows the display when testing an 18m-long SMA-SMA cable with a short circuit at the far end. The step falls back to zero after about 191ns, as you'd expect.

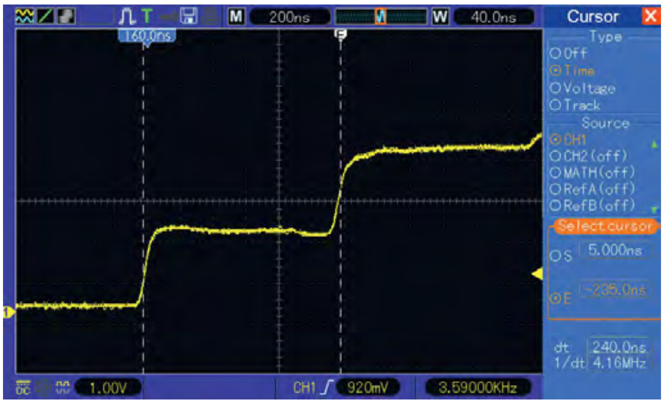


Fig.10: this scope grab shows the display when testing a 22.6m long SMA-SMA cable which was open-circuited at the far end. In this case, the step jumps up to twice its initial value, after about 240ns.

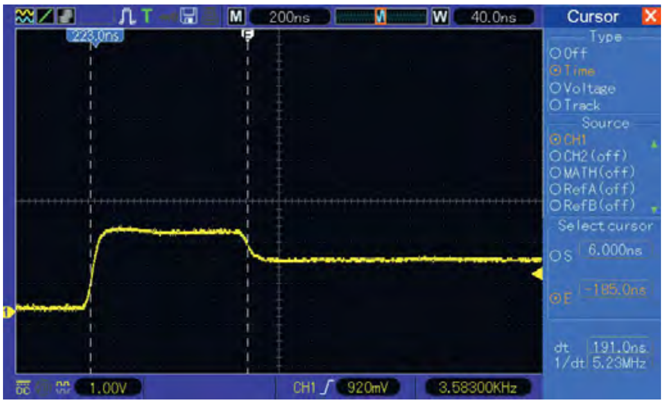


Fig.11: finally, here's the display when testing an 18m long SMA-SMA cable terminated in a 25Ω load instead of the correct 50Ω. As you can see, there's a step down by about 1/3 of the initial value, about 191ns from the start.

TDR Dongle hooked up to a Tekway DST1102B DSO.

We checked three different RG-58/U cables, all fitted with SMA connectors. Fig.8 shows the display with a 4.6m cable, which was correctly terminated in 50Ω at its far end. As you can see, the step continues smoothly way past the 50ns point corresponding to this cable length (indicated by the second vertical cursor), showing that the cable was indeed correctly terminated.

Compare this with the display in Fig.9, which shows an 18m-long cable with a short circuit at the far end. In this case, the step drops back to zero about 192ns from the start and if you check with the chart of Fig.7, you'll see that this time corresponds to a cable length of very close to 18m.

Fig.10 shows the display with a 22.6m-long cable with an open circuit at the far end. Here the step jumps up to twice its initial value, after a reflection time of about 240ns. If checked against Fig.7, you'll see that this corresponds to a cable length of very close to 22.6m.

Specification

- A low-cost voltage step generator for use with an oscilloscope to enable time-domain reflectometry measurements of coaxial cables.
- The main output provides repetitive voltage steps with a duration of 30.5µs, allowing for observation of reflections over cable lengths of up to just over 3km (in common cables with 'solid PE' dielectric). Step rise-time is approximately 26ns.
- Output impedance is selectable between 50Ω, 75Ω or 100Ω, to suit most common coaxial cables.
- A second output provides negative-going steps 30.5µs ahead of the main output steps, to allow pre-triggering of the scope via its external trigger input.
- Both outputs are provided via SMA connectors.
- The adaptor is powered from 5V DC, which can be sourced from a USB port on a DSO, a PC or tablet, or a low-cost USB charger.
- Current drain is typically 16-20mA. A 3mm green LED provides indication that the generator/adaptor is operating.

Finally, Fig.11 shows the display when the 18m cable was deliberately mis-terminated with a 25Ω load at the far end. This causes a step down about 191ns from the start, with an amplitude that's very close to 1/3 that of the incident step. This is close to what you'd expect with a load impedance of Zo/2.

So these screen grabs should give you a good idea of what can be achieved. Happy cable testing!